SIRTF telescope test facility

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ABSTRACT

An optical test Dewar has been constructed with the unique capability to test mirrors of diameter $\leq$ 1 m, f $\leq$ 6, at temperatures from 300 to 5 K with a ZYGO Mark IV interferometer. The facility possesses extensive thermometry throughout for characterization of the test chamber thermal environment and Dewar performance. Optical access is controlled with cryogenically cooled shutters. The entire Dewar is vibration isolated by 40 dB where the fundamental resonances of the Dewar structure are highest. The facility has been brought on line for its first user, the Infrared Telescope Technology Testbed (II"IT) for the Space Infrared Telescope Facility (SIRTF) at JPL. The design requirements for this facility and the resultant design and implementation experiences and challenges will be presented.

Keywords: Infrared, cryostat, telescope, SIRTF

2. INTRODUCTION

In the astronomical community there is clearly the desire for large spaceborne optical systems. Due to NASA's desire to produce smaller, lighter, lower cost spacecraft, there exists an effort to develop large lightweighted optics. In order to mitigate the risk of using these new lightweight technologies, it has been necessary to build a facility to permit the testing of these systems. In keeping with NASA's desire to simplify and reduce the cost of flight operations, the Jet Propulsion Laboratory (JPL) undertook the task of a quick development, low cost facility for the optical interferometric testing of mirrors of diameter $\leq$ 1 m, f $\leq$ 6, at temperatures from 300 to 5 K. The project was constrained by an allocation of one year in which to complete the design, fabrication, and optical qualification test, with funding commensurate with the allotted schedule. The system design performance was traded off against cost to minimize the resources necessary to develop the system yet still meet the requirements for cryogenic optical testing. The Dewar, instrumentation, vibration isolation and support equipment were all treated in the trade space. The facility requirements were that the system environment be stable enough for $\lambda/40$ rms interferometric measurements with a helium neon laser interferometer, the Dewar conveniently permit disassembly for mounting the test apparatus, and that all surfaces in the test chamber reach 8K. Two goals of the facility were to reach equilibrium in no more than 72 hours and that cryogen hold time be at least 72 hours.

The approach was the use of a small, dedicated team with an industry partner (Janis Research Co., Inc.) for the Dewar fabrication. Specific expertise was procured on an as needed basis. Another part of the approach was to use, to extent possible, hardware inherited from previous JPL projects.

3. GENERAL FEATURES

3.1. Dewar structure

The Dewar has a vertically oriented inner cylindrical test chamber with a diameter of J .-1 m and an internal height of 2.3 m. The experiment mounting surfaces, the upper and lower surfaces of the chamber, are the exterior surfaces of two liquid helium tanks. The upper liquid helium tank may be positioned at any height within the cylindrical wall of the test chamber to facilitate the testing of optics with various focal lengths. The cylindrical wall of the test chamber is conductively cooled by two 300 liter capacity tanks. All exterior helium cooled surfaces (tank walls and shroud) are covered with a single layer of aluminized mylar to raise the surface emissivity[1]. Surrounding the test chamber is an aluminum dome covered with a 10 layer multi layer insulation (MLI) blanket made of layers of aluminized mylar with spacer material[2]. This dome is conductively cooled through a bolted contact joint with a 300 liter capacity liquid nitrogen tank (which also has a 10 layer MLI blanket) directly below the helium cooled test chamber. The outer vacuum shell "of the Dewar is constructed of an aluminum dome that makes an O - Ring seal with a stainless lower shell surrounding the lower cryogen tanks. Structural and thermal separation between the outer vacuum shell, the nitrogen tank, and the lower helium tank is provided by titanium struts and a stainless tension/compression system necessary for earthquake safe operation of the facility in southern California. The entire Dewar is designed to withstand 1.0 g in the vertical and 0.5 g in the horizontal axis without serious

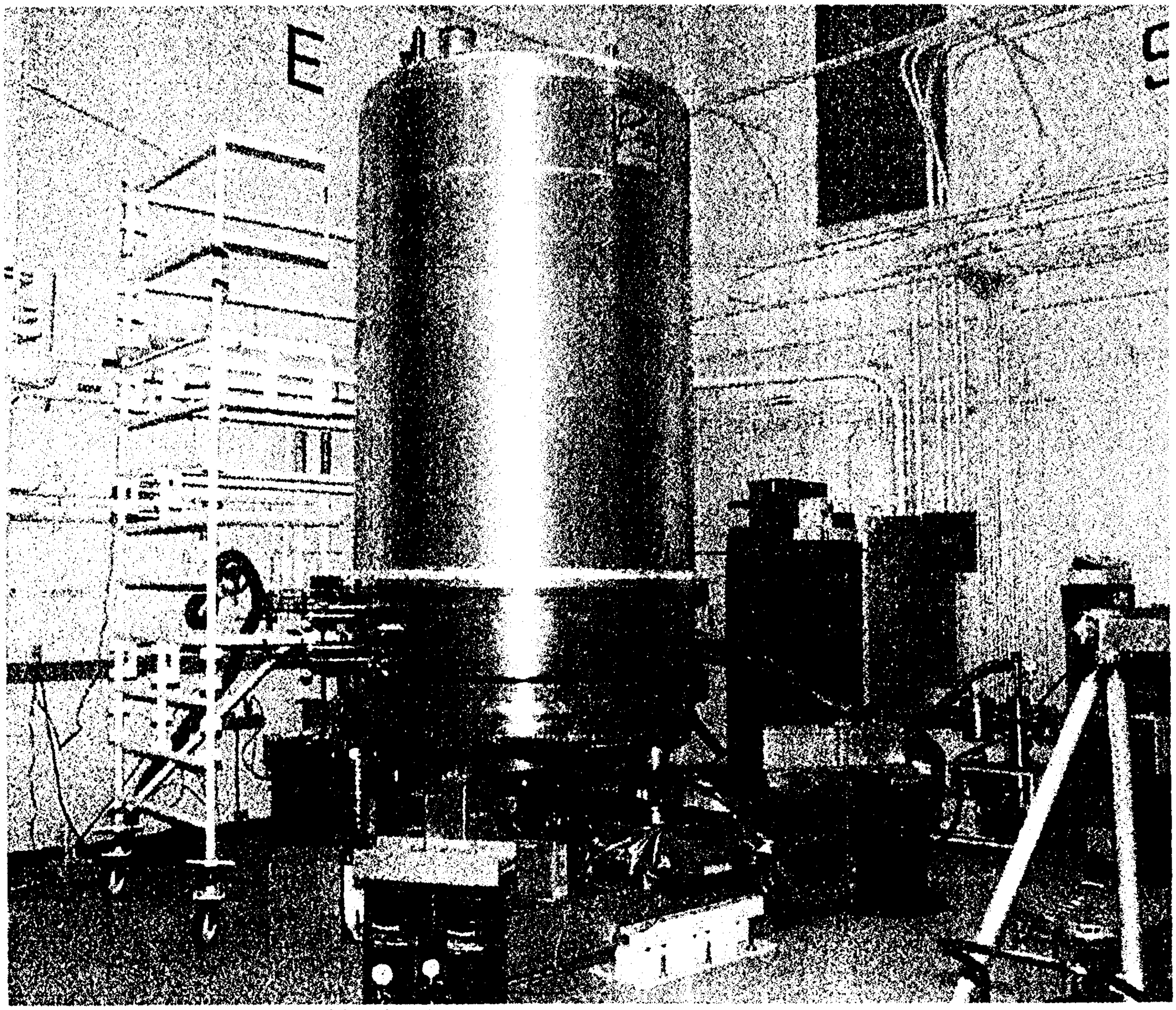


Fig. 1. SIRTF Telescope Test Facility (STTF)

hazard to human safety. Optical access is provided through a window at the bottom of the Dewar, with cryogenically cooled baffles and shutters in the apertures through the lower cryogen tanks The Dewar was fabricated through a partnering arrangement with Janis Research Company, Inc.

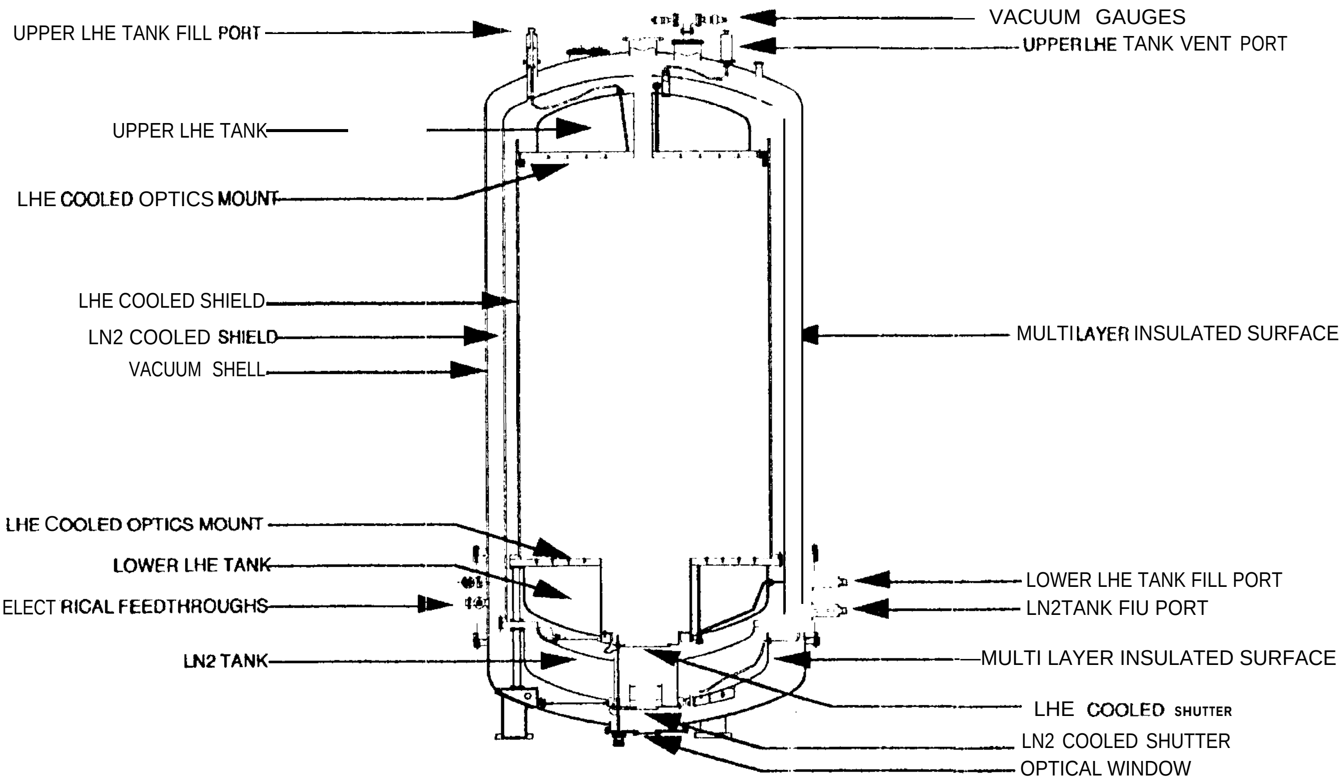


Fig. 2. STTF Dewar structure

3.2. Instrumentation

The facility possesses61 resistance thermometers with multiplexed "quasi" 4 - wire dc readout for characterization of the test chamber thermal environment and Dewar performance. All three cryogen tanks have resistive elements inside with multiplexed "quasi" 4 - wire dc readout for detection of liquid nitrogen level. Both helium tanks have superconducting helium level sensors. The Dewar guard vacuum is monitored with two pairs of cold cathode and Pirani sensors. All instrumentation control and data acquisition is accomplished with a GPIB interfaced Pentium based personal computer. Graphical user interface software written with LabView permits real-time monitoring and analysis of facility parameters.

3,3. Cryogenic optics

A two axis optical gimbal mechanism[3] for aligning 1 meter diameter telescope primaries and test flat mirrors at temperatures from 300 to 4.2 K was constructed for use in the STTF. This mechanism consists of an aluminum frame, pivoting on a monoball bearing, and driven in tip and tilt by tungsten di-sulfide lubricated lead screws with external room temperature drive motors. Flexures decouple the optical support frame from stresses generated by differential mtcs of cooling. A second set of flexures decouples the mirror mechanically and thermal] y from distortion in the gimbal mechanism. The mechanism provides arc-second resolution in either axis, while designed to limit the heat leak to less than 100 mW at 4.2 K. Linear variable differential transformers (LVDT's) were used at temperature from 300 to 4.2 K as readout for the gimbal mechanism

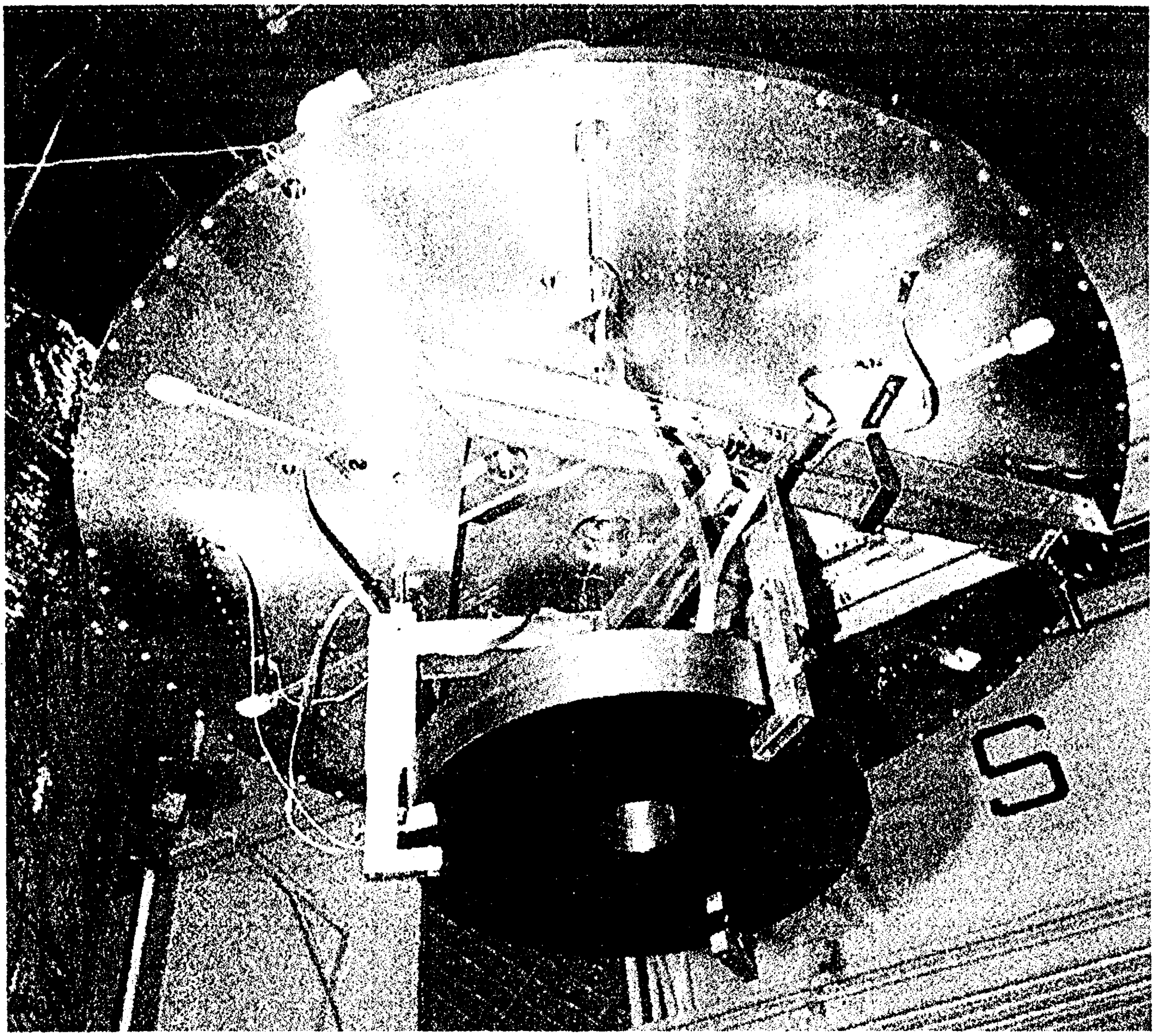


Fig. 3. Upper helium tank with gimbal and 0.5 m beryllium mirror. The Gimbal Frame is visible as a welded A-frame of 3.0 in. American Standard I-beam. A housing containing a linear variable differential transformer (LVDT) is visible to the far right of the gimbal frame. The monoball bearing pivot point is just within the apex of the A frame visible near the center of the figure.

3.4. Facility Infrastructure

The Dewar was mounted on an existing triangular vibration isolation frame that was modified to provide additional strength to meet earthquake safety requirements and to provide additional stiffening to improve stability for optical measurements. The vibration isolation frame was supported by three pairs of Newport I-2000 pneumatic isolators that have been measured to give the entire facility up to 40 dB of isolation from vibrations in the floor from 5 to 20 Hz (the dominant vibration coupling to the Dewar is through acoustic coupling to the walls of the room).

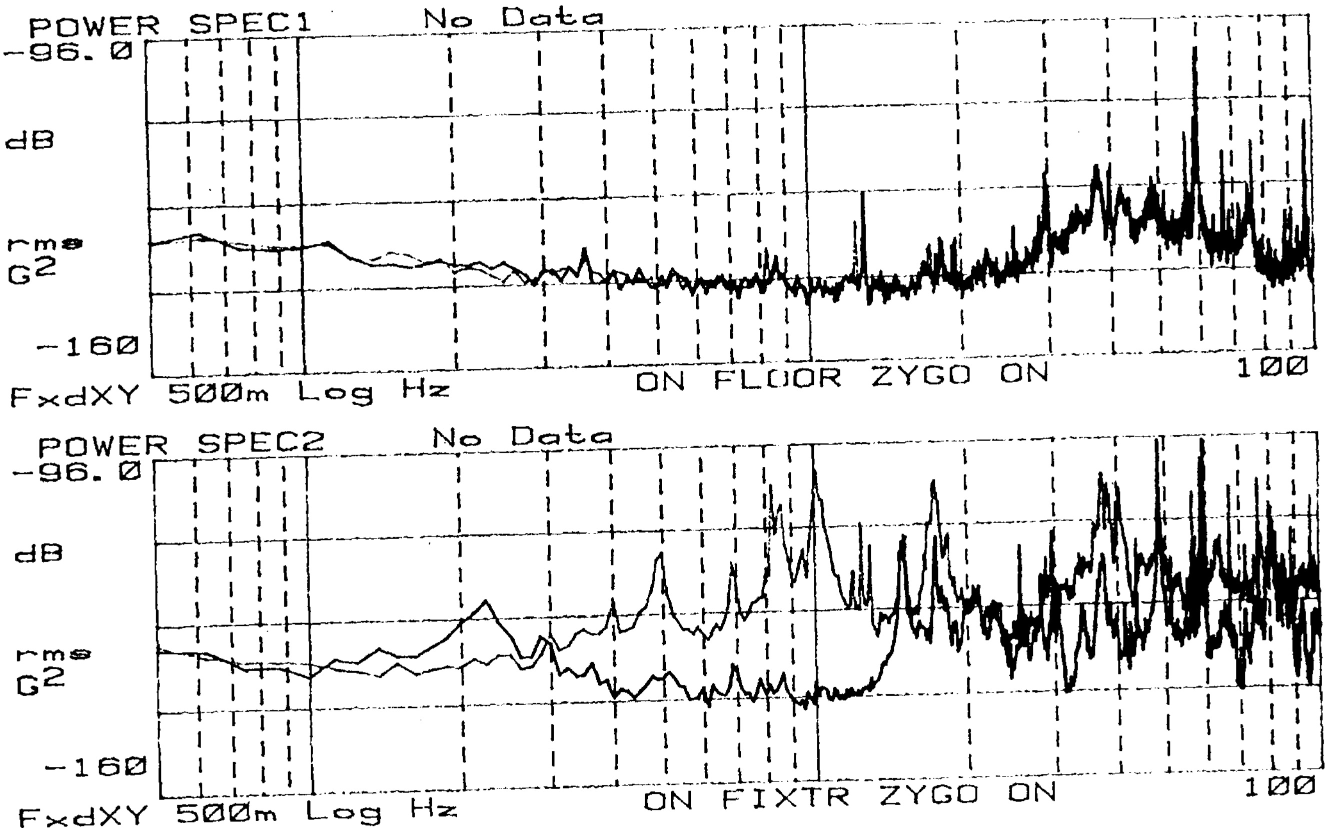
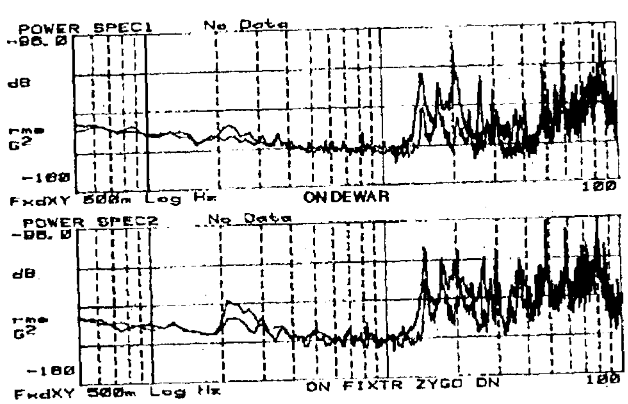
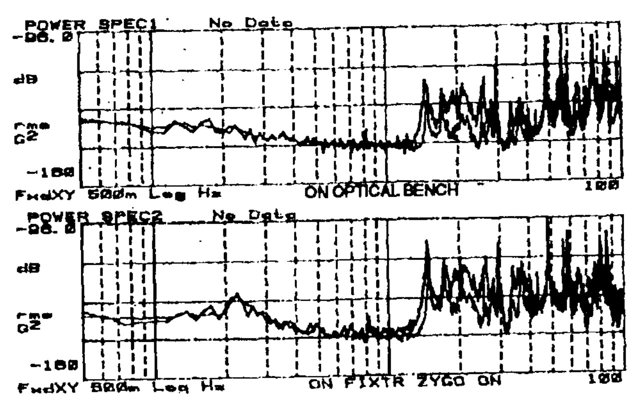


Fig. 4. Acceleration spectra for the STTF. Power spectrum 1 (upper) and power spectrum 2 (lower) are measurements of accelerometers on the Laboratory floor and the vibration isolation frame, respectively. One trace in each spectrum was taken with the pneumatic isolators activated, one with the actuators deactivated (deflated). Power spectrum 2 therefore shows the up to 40 dB of isolation from vibrations in the floor from 5 to 20 Hz obtained with the isolators activated for a constant floor vibration spect rum

The attachment and optical alignment of the interferometer components is achieved on standard optical breadboards bolted to the vibration isolation frame. Accelerometer spectra indicate that the vibration isolation frame, the Dewar, and the optical component mounting surfaces respond as a single unit to external vibration.



(a)



(b)

Fig. 5. Acceleration spectra comparisons for: (a) the Dewar (1) and isolation frame (2), and (b) the optical bench (1) and isolation frame (2) with the laboratory air condit ioning on and off. The results are interpreted to indicate that the vibration isolation frame, the Dewar, and the optical component mounting surfaces (optical bench) respond as a single uni t to external vibration

The facility includes a 3 ton bridge mane with hydroset for ultra slow vertical speed capabi li ty for assembly and disassembly of the Dewar. The facility also includes a servicing scaffold on casters for assembly, disassembly, and cryogenic servicing 01 the Dewar.

The Dewar vacuum is achieved with a 400 liter scc turbomolecular pump through 4 inch flexible pump lines. The facility also includes a helium leak detector for testing of assembled components.

4. CRYO-SERVICING

4.1. Liquid nitrogen cool down

After achieving a guard vacuum of better than 10^{-4} Torr in the Dewar, the cool down begins with the introduction of liquid nitrogen into all three cryogen tanks simultaneously. Cool down is achieved by first cooling the tank walls adequately to accumulate liquid inside and fill the tanks, with the conductively cooled surfaces then relaxing to equilibrium with a longer time constant. Cool down to steady state took about 72 hours and required approximately 3000 liters of liquid nitrogen when transferring at an average rate of 9 liters/hour into each tank

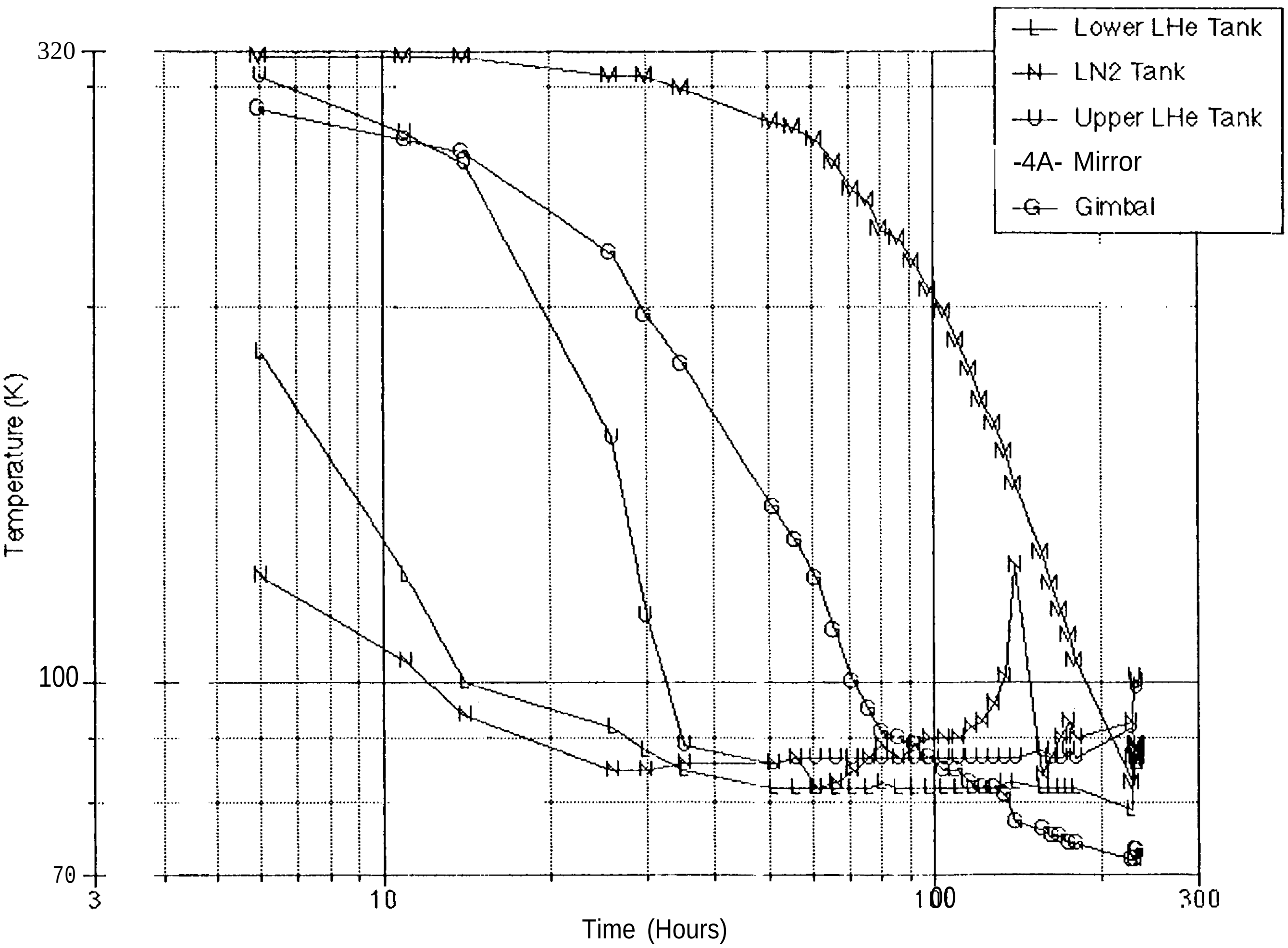


Fig. 6. Temperatures within the STH as a function time during the liquid nitrogen cool down. The temperature of the beryllium mirror lagged the Dewar temperature duc to its large specific heat.

4.2. Liquid nitrogen steady stale performance

At steady state, with liquid nitrogen in ail three tanks, the parasitic heat load (as measured by cryogen boil off rate) to the upper helium, lower helium and nitrogen tanks were 2.4 W, 2.8 W and 99 W, respectively. This provides nearly 6 days cryogen lifetime in the nitrogen tank and 200 days lifetime in the helium tanks.

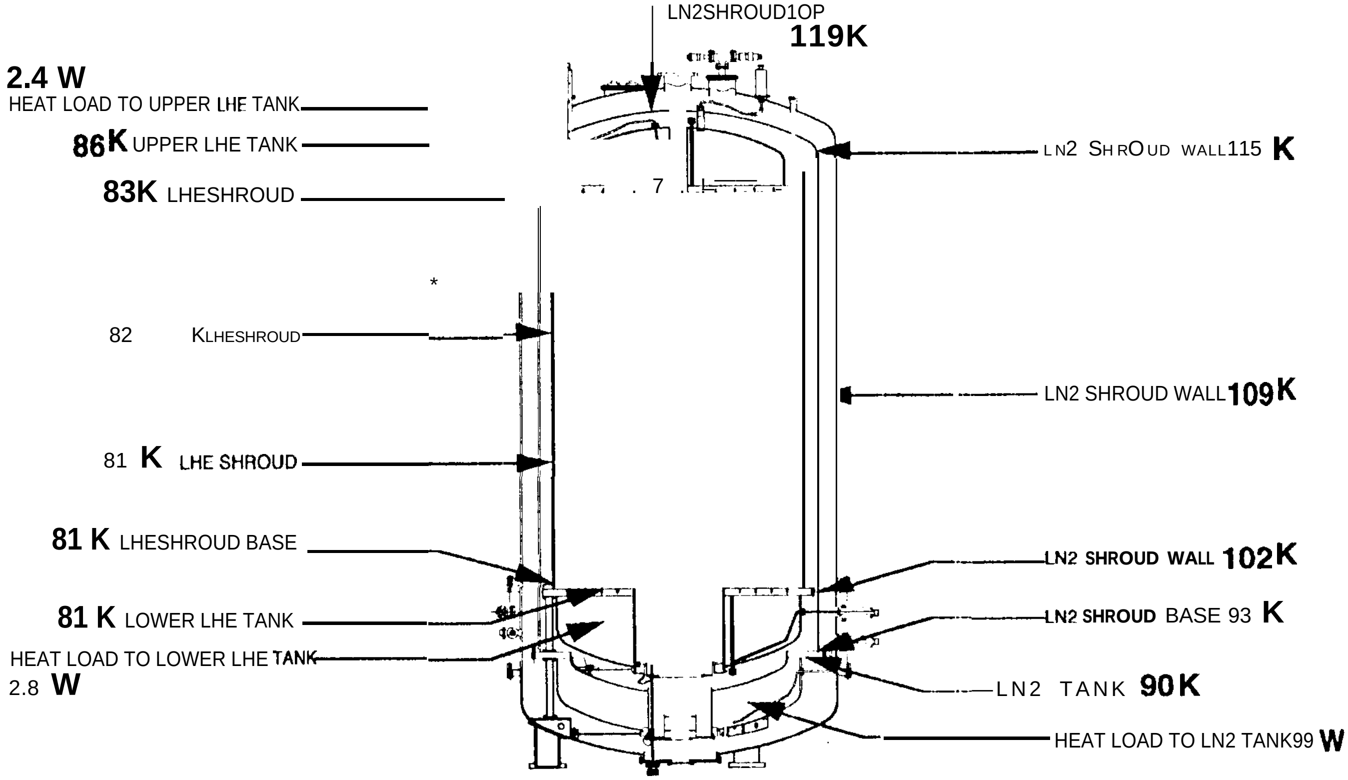
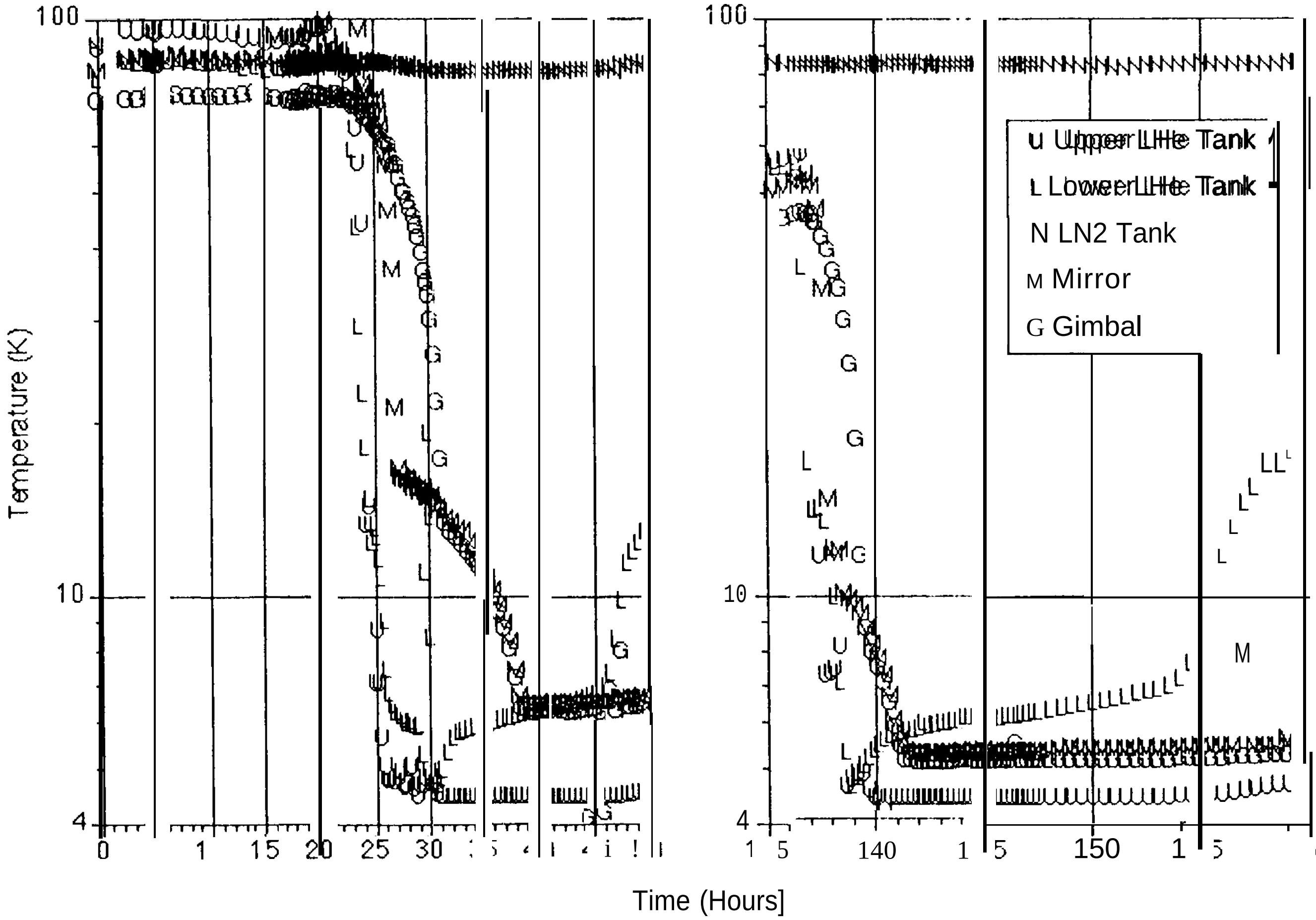


Fig. 7. Steady state performance of the STTF with liquid nit rogen in al 1 three tanks

4.3. Liquid helium cool down

To cooi the test chamber below liquid ni trogen temperatures, any remaining liquid ni trogen is purged from both liquid hcli um tanks by over pressuring the tanks wi th helium gas. Liquid helium is then transferred iuto both tanks simultaneously. Cooi down is achieved by first cooling the tank walls adequately to accumulate liquid inside and fill the tanks, with the conductivel y cooled surfaces then quickly relaxing to equilibrium. Cool down to steady state took about 2-i hours and required approxi mately 1200 Ii tcrs of liquid helium when transferring at an average rate of 1 lit@ mi nute into each tank. At steady state the guard vacuum was approximately 3 x 10-6 Torr in the Dewar.



1 ;jt. 8. Temperatures within the STTF as a function time during two liqui d helium cool downs. The transfer of liquid helium began at O hours. During the first cool clown the lower helium tank was not filled adequately and a second transfer was initiated into both tanks 135 hours after the initiation of the first in order to characterize the equilibrium behavior of the system.

4.4. Liquid helium steady stale performance

At steady state, with liquid helium in both the upper and lower helium tanks, and liquid nitrogen in the nitrogen tank, the parasitic heat load (as measured by cryogen boil off rate) to the upper hel ium, lower helium and nitrogen tanks were 2.2 W, 9.7 W and 57 W, respectively. This provides nearly 10 days cryogen lifetime in the ni trogen tank. A thermal model has shown that the thermal profile and the difference in the boil off rates in the upper and lower helium tanks are consistent with a factor of 4 difference in the thermal conductivity of the links between the helium shroud and the upper and lower helium tanks respectivel y. A minor modification has been made to the upper tank mounting scheme that should provide over 36 hours of cryogen Ii fetime in both helium tanks. A thermal model has also verified that the thermal profile and heat loads arc consi stent with radiation dominated heat loads. This thermal model indicates that over 95% of the heal load to the nitrogen cooled surfaces and over 66% of the heat load to the helium cooled surfaces are radiati ve in nat ure.

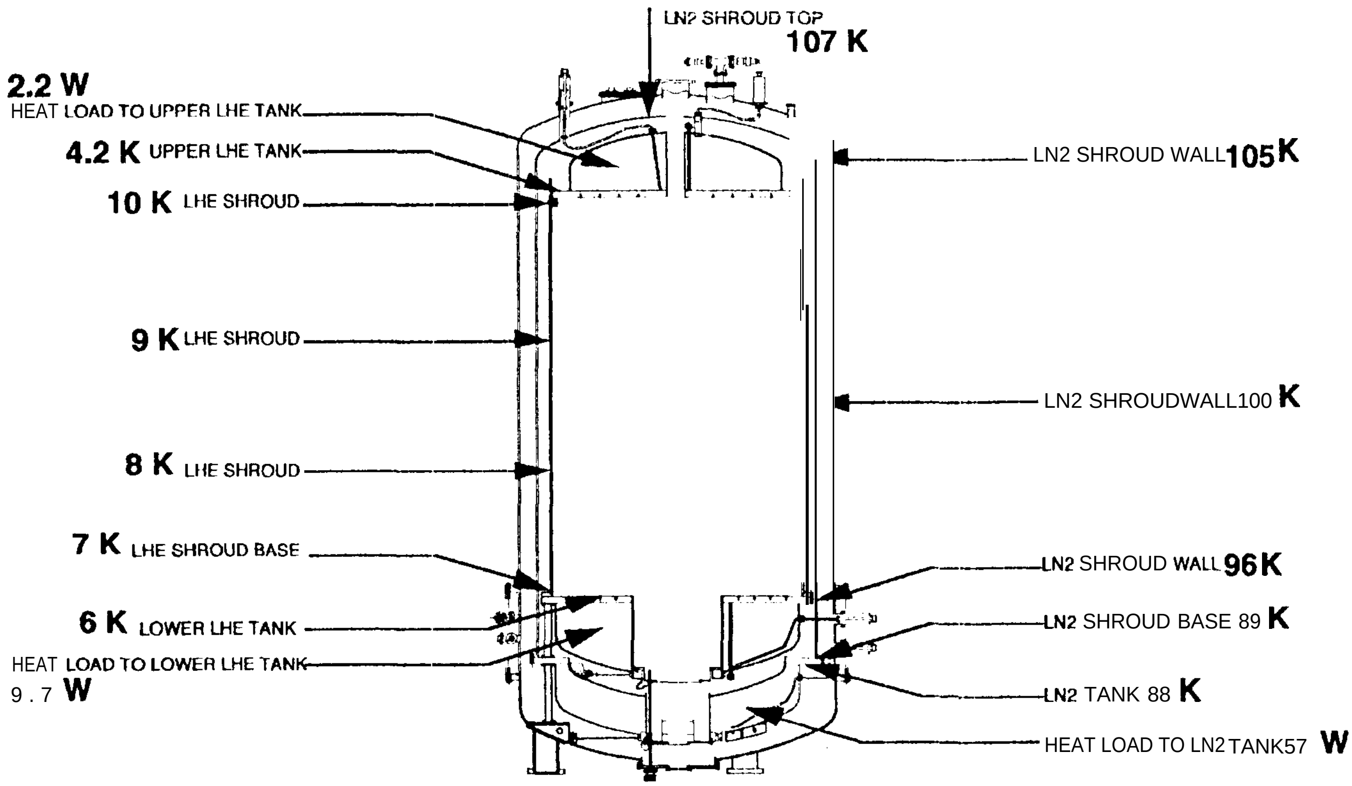


Fig. 9. Steady state performance of the STTF with liquid helium in both helium tanks, and liquid nitrogen in the nitrogen tank. A minor modification has been made to the upper tank mounting scheme and should provide a more even distribution of the heat load between the upper and lower helium tanks. In addition, it is predicted that with this modification the liquid helium shroud temperature will not exceed 8.5 K.

5. OPTICAL MEASUREMENTS

The facility was optically qualified using a 0.5 beryllium mirror that had been extensively characterized in a 0.5 m facility at AMES Research Center. Direct comparison of the interferograms obtained at each equilibrium temperature (nominall y 300K, 77K & 4.2K) and the difference in the interferograms obtained at each equilibrium condition provided the figures of merit for qualifying the facility. The better than $\lambda/40$ interferograms obtained in the STTF at mirror temperatures of 300K, 80K and 6.5K during regular business hours were similar to those obtained in the AMES facility. Although the mirror was later cooled to 5 K, a mechanical problem with one of the shutters, which has since been repaired, precluded obtaining an interferogram at this temperature. The differences in the interferograms obtained at each equilibrium temperature were nearl y indistinguishable from those obtained in the AMES facility. These results were interpreted to qualify the facility for cryogenic interferometric measurements.

6. SUMMARY

Developed by the Jet Propulsion 1 Amatory's Low Temperature Science and Engineering Group in Section 3.S4, the SIRTF Telescope Test Facility (STTF) was completed, from conceptual design through construction and evaluation testing, in less than onc year and within the allocated budget. The systcm has been qualified as meeting the performance criteria both cryogenically and opticall y. The facility has the unique capability to conduct interferometric tests of mirrors of diameter $\leq$ 1 m, $f \leq 6$, at temperatures from 300 to 5 K. The facility includes instrumentation for characterization of the test chamber thermal environment and Dewar performance.

A second test of the facility at helium temperatures is in progress, and a test of the Infrared Telescope Technology Testbed (ITTT) for the Space Infrared Telescope Facilit y (SIRTF) is scheduled for early summer 1995.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] More than a single layer has been shown ineffective at low temperatures. See 1. Ii. Spradley, '1'. C. Nast, and D.J. Frank, "Experimental studies of MLI systems al very low boundary temperatures", *Recent Advances in Cryogenic Engineering*, Vol. *35, pp. 477-485, 1990.*

[2] Ten layers was chosen to meet the design performance requirements while minimizing fabrication cost and schedule. See 1. C. Nast, "A review of multilayer insulation, theory, calorimeter measurements, and applieations", Recent Advances in *Cryogenic Engineering*, Vol. *267,* ***pp. 29-43, 1993.***

[3] R G. Chave, A. E. Nash, J. Hardy, "Gimbal mechanism for cryogenic alignment of 1 meter diameter optics", *submitted to SPIE's 1995 International Symposium on Optical Science, Engineering and Instrumentation, Optomechanical and Precision Instrument Design Conference, San* Diego, 19!!5.